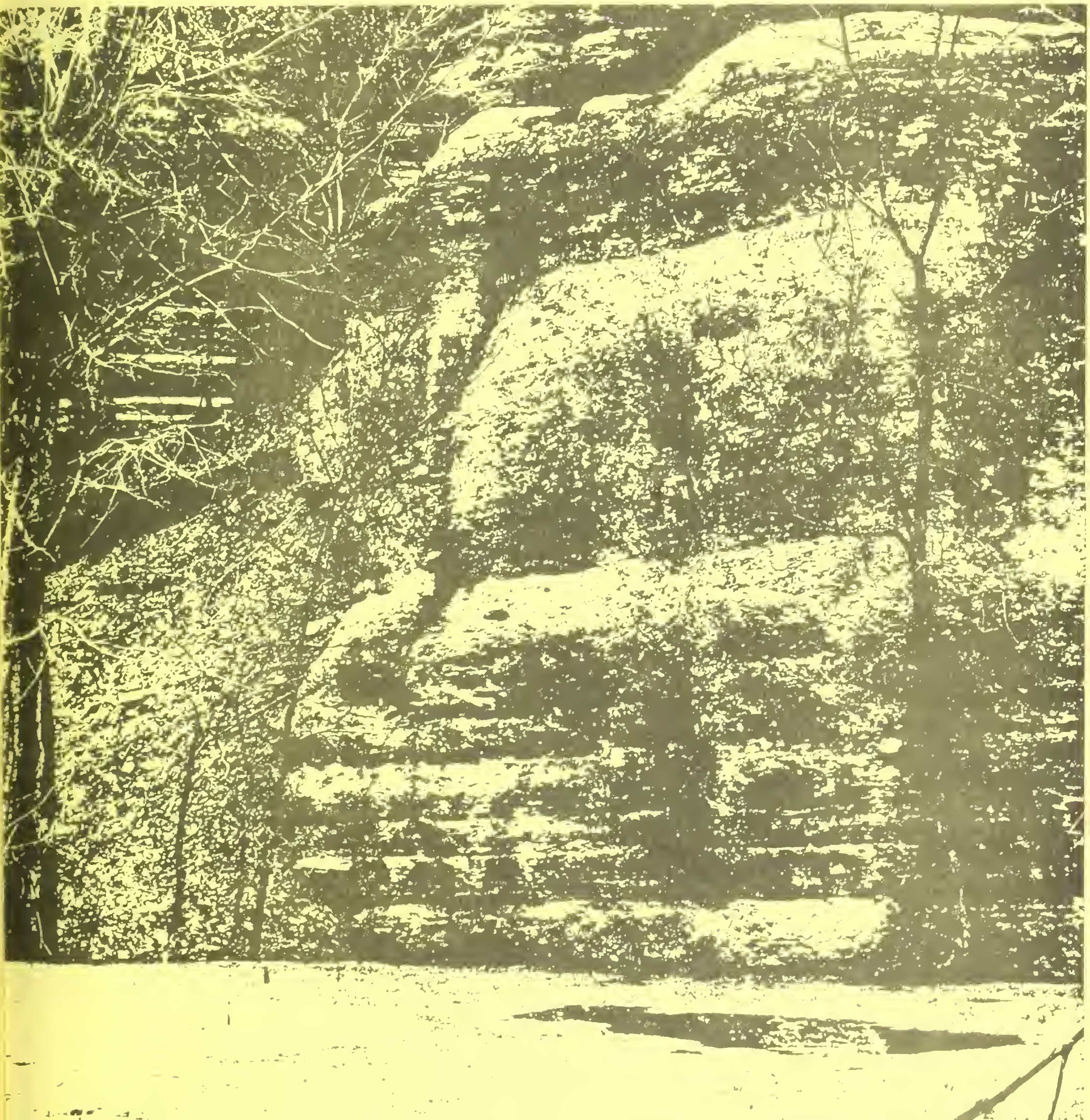
Geol Survey

Ground-water geology of selected wetlands in Union and Alexander Counties, Illinois

E. Donald McKay
Atef Elzeftawy
Keros Cartwright



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COVER PHOTO: Wetland area fed by spring discharge at the base of the Mississippi Valley bluffs in the La Rue-Pine Hills natural area, Union County. A small, 20-liter per minute, spring discharges from a horizontal parting in the cherty limestone of the Devonian age Bailey Limestone.

McKay, E Donald

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ABSTRACT

Preliminary evaluation of the ground-water systems in selected wetland areas in the Mississippi River Valley was undertaken to identify the potential impacts from proposed surface drainage improvements on wetlands in the Big Five Drainage and Levee Districts, Union and Alexander Counties, Illinois.

Field studies included geologic mapping, description and sampling of geologic materials from 37 borings, description of materials in surface exposures, temperature measurements at points of ground-water discharge, and installation of 12 piezometers to monitor ground-water levels and flow. In the laboratory, water-conducting properties of all major strata were measured to facilitate estimation of the volumes of water moving in response to gradients measured in the field.

The results of this preliminary study show that ground-water movement in wetland areas is controlled by a complex interplay of local and regional factors. Ditching and other drainage improvement in the vicinity of wetlands will undoubtedly alter local ground-water levels and flow directions. The magnitude of the induced alteration can be predicted only from long-term study of spatial and temporal variations in the ground-water system. In volumetric terms, the ground-water contribution to a wetland appears to be minor in relation to other factors; however, it is clear that a small change in the ground-water system may have a dramatic effect on the permanence of wetland areas.

INTRODUCTION

Natural wetland areas occur on the broad alluvial plain of the Mississippi River in Union and Alexander Counties in extreme southern Illinois (figure 1). In this region, designated the Big Five Districts, the modern Mississippi channel is directly against the bedrock upland that forms the western edge of the valley. The alluvial plain, extending eastward from the main river channel to the bedrock upland that forms the eastern valley margin, ranges from 6 to 10 kilometers (3.7 to 6.2 miles) in width. The northern boundary of the districts is Big Muddy River. Along the eastern valley margin, the La Rue Swamp in the north and Clear Creek in the south form the eastern boundaries of the district. The western and southern limits of the district parallel the main channel of the Mississippi River which flows along the western bedrock bluff to a point just south of Cape Girardeau, Missouri, where it turns east and passes through the narrow bedrock gorge near Thebes. Land use of the alluvial valley in the Big Five District is predominantly agricultural, though there are several small communities, including Ware, McClure, Wolf Lake, and East Cape Girardeau, and some large wildlife refuge areas.

Many wetland areas occur in this region in highly varied hydrogeologic settings. The purposes of this study are to establish a data base for an understanding of the hydrogeologic setting of selected wetland areas in the Big Five Districts and to determine how hydrogeologic conditions influence both the occurrence of wetlands and the impact of drainage improvements on wetlands. The principal study sites (figure 1) are {1} the La Rue Swamp (Sections 9, 16, 21, 28, T. 11 S., R. 3 W., Union Co.), {2} the Big Five north wetland (Sections 1 and 2, T. 13 S., R. 3 W., Union Co.), and {3} the Big Five south wetland (Section 29, T. 14 S., R. 3 W., Alexander Co.).

Regional Geologic Setting

The Mississippi River in the study region occupies a valley cut deep into Paleozoic bedrock. The valley bluffs are principally Lower Devonian limestones and cherts. In the valley bottom deep wells have penetrated Lower Devonian rocks in the northern part of the area, Silurian dolomites from Wolf Lake south to McClure, Ordovician shales southwest of McClure, and Ordovician dolomites in the East Cape Girardeau area.

It is difficult to determine precisely when the valley was first downcut into the bedrock surface. Flint (1941) concluded that the position of the Mississippi Valley on the eastern flank of the Ozarks preceded a late Tertiary uplift of the Ozark Dome. Other workers, notably Trowbridge (1921), have suggested that, because most of the deep bedrock valleys of the Upper Mississippi Valley lie near the margins of early glaciations, their positions are determined by the glaciers and the entrenchment is

more recent than late Tertiary, probably entirely Pleistocene in age. Regardless of whether entrenchment was accomplished in the late Tertiary or during the early Pleistocene, the downcutting of the bedrock valley in the study region probably occurred more than a million years ago, and the valley has been occupied by a major river since that time.

During the last one to two million years, continental ice sheets advanced and receded many times on the North American continent. Though none of the advances reached the study region, the Mississippi Valley was repeatedly a carrier of meltwater and outwash sediments from the glacial margins. At times when large volumes of meltwater and sediment, principally sand and gravel, were channeled into the Mississippi, the alluvial surface aggraded as the valley was filled with coarse-grained sediments.

The last major episode of glaciation and valley aggradation, the late Wisconsinan, occurred about 25,000 to 10,000 years ago. The elevation of the aggraded outwash surface in the main channel during the late Wisconsinan is recorded by terrace remnants in the valleys of bluff tributaries. As the Mississippi aggraded, tributaries were dammed at their mouths by outwash. Slackwater lakes formed in the tributary valleys and were filled with lake deposits. Remnants of lake sediments form terraces in Dutch and Clear Creeks (Union Co., Illinois) and Apple Creek (Perry Co., Missouri). These indicate an elevation of maximum late Wisconsinan aggradation of 116 to 119 meters (380 to 390) feet) above mean sea level.

During the last 10,000 years, the general trend has been one of degradation, lowering of the alluvial plain, leaving the late Wisconsinan slackwater terraces 9 to 12 meters (30 to 40 feet) above the present floodplain. There have probably been several reversals of this trend, but no traces remain of young aggradation surfaces higher than the modern surface, and data are insufficient to identify lower levels.

The tendency of a meandering river, especially one confined in a narrow bedrock valley, is to migrate across the alluvial plain from bluff to bluff. In the study area, the Mississippi River has probably migrated back and forth across its floodplain several times in the last 10,000 years. During migration, the main channel has reworked the upper part of the older outwash and alluvium. The present thickness of valley-fill sediments exceeds 35 meters (115 feet) along the axis of the valley. The sediments generally coarsen with increasing depth, and the coarse sand and gravel near the base of the sequence have probably not been reworked since their deposition in the late Wisconsinan.

The upper alluvial fill has been reworked periodically and contains a complex sedimentary history of geologically recent channel migration. Figure 1 shows the major physiographic subdivisions of the study area, including ridge and swale topography, natural levees, and abandoned channels. All of these features are characteristic of the landscape produced by meandering river migration.

Migration of a river channel is explained by distribution of flow velocities within the stream. High velocities are found in deep water in

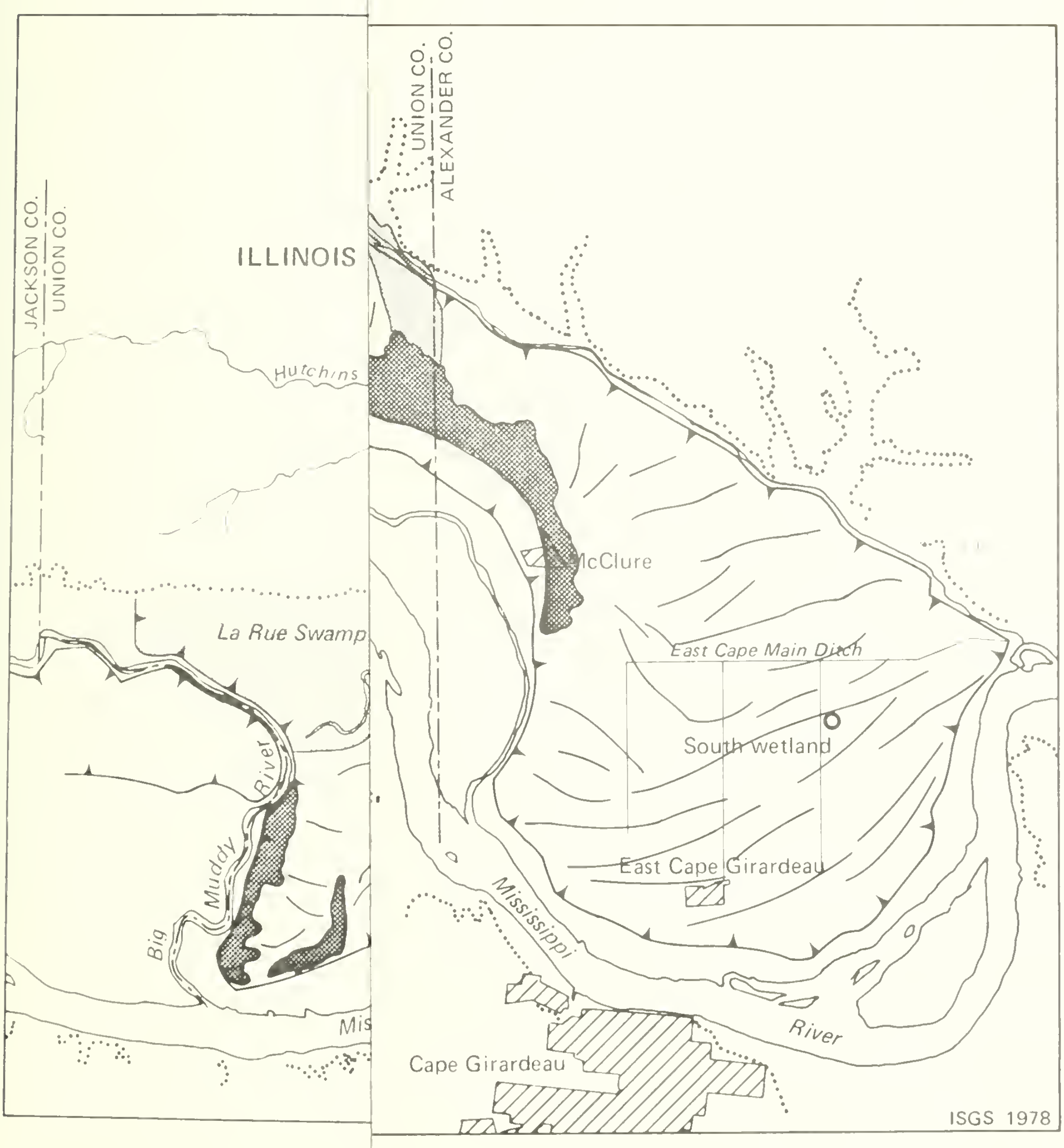


Figure 1. Physiographic

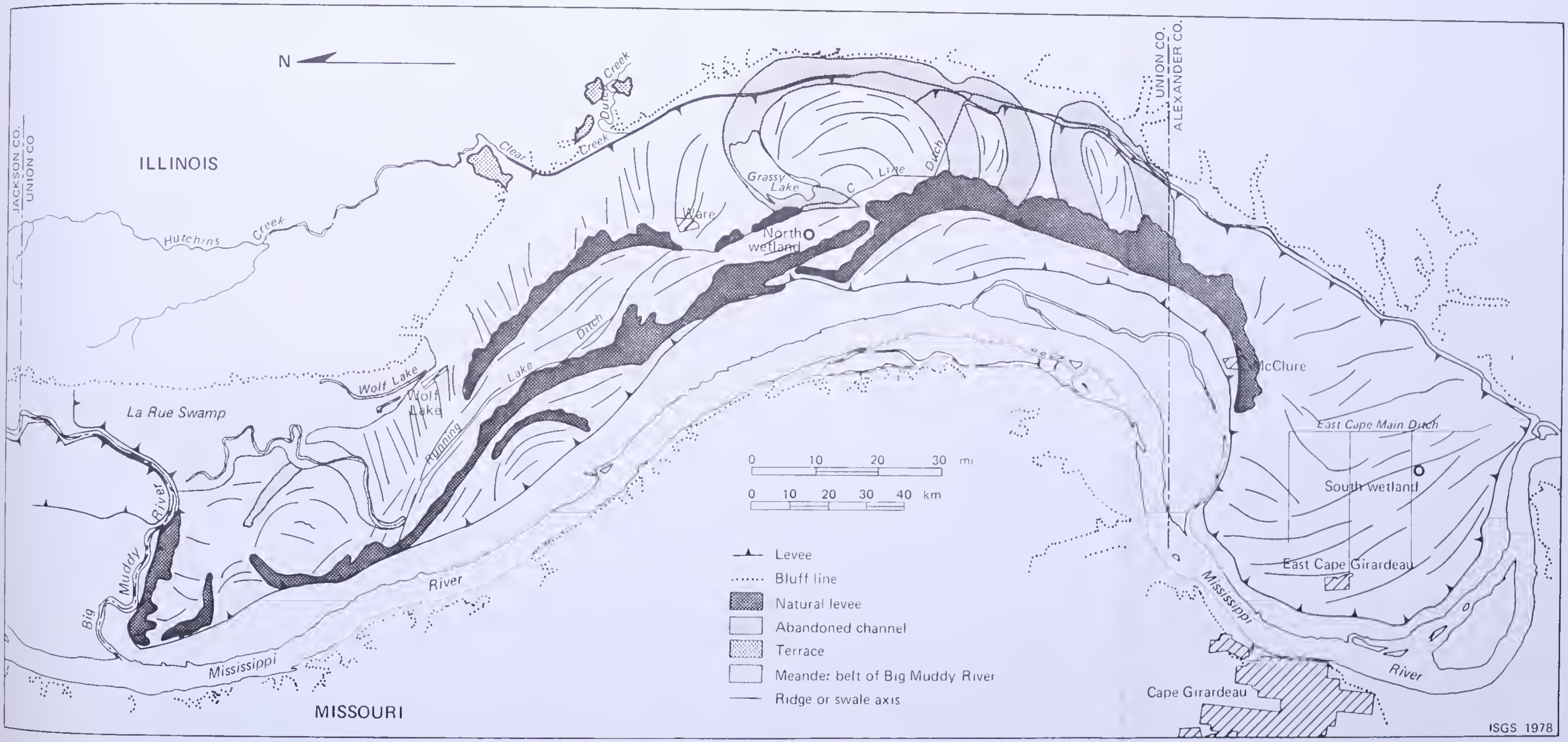


Figure 1. Physiographic regions of the Big Five Drainage Districts

the outer portion of the meander bend. Impingement of high velocity flow lines against the concave bank concentrates erosion in that area. Materials eroded from the outside bend are generally transported downstream with coarse bed load material accumulating on the convex bank (point bar) of the next meander. Each meander loop, active or cut off, encloses a point bar formed of ridges and swales roughly conformable with the curve of the channel. A ridge represents an aggradation of bed load material against the convex channel bank during a flood. The ridges enclose low-lying swales often holding marshes, ponds, or shallow arms of the stream.

Natural levees are broad ridges constructed of bed load material dropped by flood waters as they rise and spill out of the central channel. Their elevation is greatest close to the edge of the channel, and from there they gently slope away into the flood basins. Levees are best developed along concave banks of the stream and are commonly .4 to .8 kilometers (.25 to .5 miles) wide in the Big Five Districts. Levee deposits become finer away from the channel and grade laterally into very finely textured topstratum floodplain deposits.

During stream migration, channels are abandoned by chute or neck cutoffs and are gradually filled with sediment. These channel-fill sediments can be either bed or suspended load depending on the degree to which flow is maintained through the incompletely abandoned channel.

Relative ages of meander scars can be determined from truncation of older ridge and swale trends by younger channels or point bar deposits. An examination of the ridge and swale trends in figure 1 leads to the conclusion that there are several geomorphic regions of different age, and that the oldest floodplain features occur in the eastern and northeastern portions of the Big Five District.

One of the oldest abandoned channels on the floodplain is now occupied in part by Grassy Lake. Two radiocarbon dates from wood preserved in the channel-fill sediments have recently been determined by the Illinois State Geological Survey. Samples of wood from alluvial sands at depths of 14 meters (46 feet) and 23 meters (76 feet) in a water well located in the NE¼ NW¼ SW¼ Section 32, T. 12 S., R. 2 W. yielded ages of 1970 $\pm$ 75 B.P. radiocarbon years (ISGS-453) and 2060 $\pm$ 90 B.P. radiocarbon years (ISGS-454), respectively.

These dates indicate several things about recent floodplain history:

(a) The position of the Grassy Lake meander in relation to adjacent meander features indicates that surficial sediments in the areas of both the Big Five north and south wetlands are younger than those in the Grassy Lake meander and were deposited less than 2000 years before present.

(b) The depth of scour of the Mississippi channel when it occupied the Grassy Lake meander was greater than or equal to 23 meters (76 feet).

(c) The similarity of the two dates indicates that the filling of the lower portion of the Grassy Lake meander took place rapidly.

Floodplain features older than the Grassy Lake meander occur north of the meander along the eastern margin of the valley. A region of east-west oriented ridge and swale north of Grassy Lake (figure 1) is clearly older than the meander and probably formed during the southward migration of that meander. Older still is the meander belt of the Big Muddy River in the northeastern part of the region (figure 1). Small scale meander scars, e.g. Wolf Lake, attributable only to a stream the size of the Big Muddy, occur within this region. Clearly, the meandering pattern of ridges and swales and abandoned channels in the La Rue Swamp are traces of a former course of the Big Muddy.

Ground Water in Alluvial Valleys

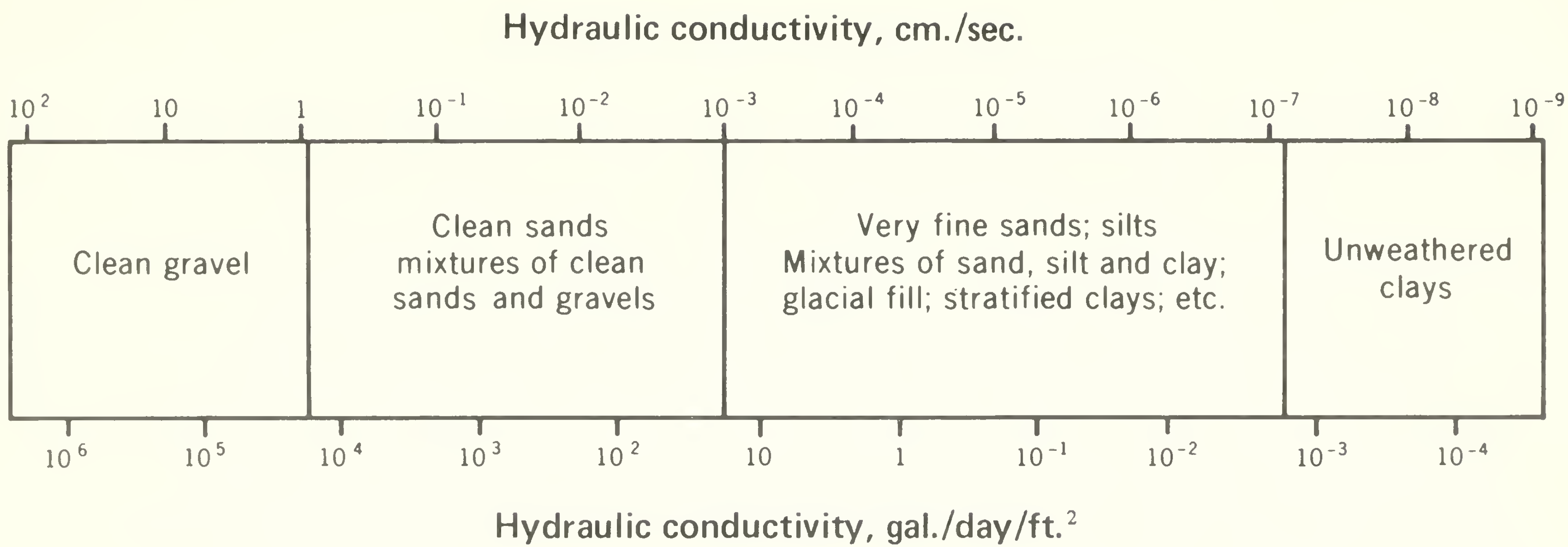
Many aspects of hydrogeology are, as yet, of special interest only to scientists; nevertheless, it is a branch of earth sciences which has in large measure been born out of practical interests and considerations. Indeed, one of the many problems of great economic importance is the understanding of ground water and its transport behavior in alluvial valleys. Sharp (1976) stated that the floodplain of a major river is an area of large potential for agricultural resources, extensive recreational usage, disposal of wastes, and wildlife habitat. He also mentioned that accurate knowledge of the existing hydrogeologic regime is required to avoid causing irreversible damage to this major alluvial valley resource.

A discussion of the hydrogeology of the wetland environment must begin with the basic principles of ground-water flow. Ground water moves from levels of higher energy to levels of lower energy. Its energy is essentially the result of elevation potential. While flowing, ground water experiences a loss in energy due to friction against the walls of the granular medium along its seepage path. This loss per unit length of distance traveled or hydraulic gradient, is simply proportional to the velocity of ground water. Expressed mathematically, the relationship between the hydraulic gradient (∇H) and the Darcy velocity (V) of ground water (flux, i.e. discharge per unit area per unit time) is as follows (Darcy, 1856):

$$V = -K\nabla H \tag{1}$$

where K is the proportionality constant and is called the hydraulic conductivity of the granular medium. The value of K, expressed in centimeters per second, depends on properties of the fluid as well as on characteristics of the medium. Table 1 shows a list of typical values of K for some geologic deposits. For an isotropic sandy alluvial deposit, typical values of hydraulic conductivity could range between 1×10^0 and 5×10^{-5} cm/s. Significant vertical variations in alluvial hydraulic properties due to the vertical variation in the grain size of the deposits should be antic-

Table 1. Typical values of hydraulic conductivity
(after Hughes, 1972)



ipated. Mansur and Kaufman (1956) published typical cross sections of the Mississippi River. Their results, which parallel the finding of this study and a recent study of Bergstrom et al. (1968), show that the deepest alluvium often consists of gravels, whereas sediments in the top stratum are most commonly silts and other fine sediments. Mansur and Kaufman (1956) indicated that the general pattern of grain size of the alluvial sediments could be described by an exponential relation with depth. They also correlated the hydraulic conductivity (K) with depth of the alluvium (Z) by the following relation:

$$K = aZ^b \qquad (2)$$

where a and b are empirical constants.

Rivers and streams can be classed in general as influent or effluent: influent if they flow above the level of the water table in the adjacent land, contributing water to the ground-water system, and effluent if they flow at a level below the elevation of the water table and receive water from the ground-water system.

In the relatively humid eastern United States, nearly all streams that flow perennially are effluent. In this region, rivers and streams through most of the year serve as natural discharge points receiving flow from ground-water reservoirs. However, these normally effluent streams do temporarily become influent when runoff from precipitation raises river stage above the level of the water table.

Numerous workers have investigated the complex relationship between ground-water movement in alluvial valleys and the stage variations in surface streams. Yeh (1970) proposed the following assumptions in order to simplify the study of this water transport problem:

(1) All flow is under saturated conditions.

(2) The aquifer is isotropic, homogeneous, and infinite.

(3) Upon reduction in head (river stage), water from the alluvial aquifer is discharged instantaneously.

(4) The bottom boundary of the alluvial aquifer is impermeable and horizontal.

(5) The Dupuit-Forchheimer condition of water flow is valid (mainly, the flow of ground water is horizontal).

In testing the limitations of these bank-storage model assumptions, Sharp (1977) stated that many of the assumptions greatly oversimplify the field conditions and when used in calculations may yield erroneous values.

The factors which control ground-water flow and levels in the alluvial floodplain and which must be studied for an understanding of

wetland hydrogeology are:

(1) Climatic factors. Local and regional variations in precipitation, evapotranspiration, and surface runoff are significant factors controlling ground-water levels and flow.

(2) Long-term mean river stage. The river forms the base level for the ground-water system, and changes in mean long-term stage will affect mean ground-water elevations.

(3) Short-term river stage changes and the duration of each change. A sustained flood peak will have more effect on the ground-water system than will a higher flood of shorter duration.

(4) Distance of the wetland (the observation point) from the river. The potentiometric surface farther from the river changes much more slowly and with a lesser magnitude than the surface closer to the river.

(5) Hydraulic properties of the alluvial deposits. The heterogeneities resulting from sand-filled channels, thick topstratum deposits, and stratification cause a great deal of local variation in ground-water flow.

(6) Geometry of the river and valley. Shape factors could affect ground-water flow by inducing faster or slower response to the fluctuations of river stage.

(7) Minor streams or ditches. The presence of these features on the floodplain could have an effect on promoting ground-water discharge or recharge and on maintaining permanent ground-water lows or highs.

It is apparent that many factors affect the ground-water flow in alluvial systems and, in turn, affect the hydrogeology of wetlands within the river valley. During this short study, some factors will be examined in a semi-quantitative manner. However, because of the spatial and temporal variability of many factors, long-term study is needed to understand and quantify the hydrogeology of wetlands within the Mississippi River Valley. To our knowledge, this short study is the first attempt to describe the ground-water system of alluvial wetlands in a semi-quantitative manner. A detailed study is required to estimate the regional ground-water flow, the amount of rainfall and evaporation, and the hydraulic properties of the alluvial deposits.

METHODS

A preliminary characterization of the field setting of the La Rue Swamp and the two wetland areas was made using standard reconnaissance mapping techniques. Lithologic, bedding, and structural properties of bedrock units were examined in exposures in the Mississippi bluff and the adjacent upland east of the La Rue Swamp. Temperatures of ground-water discharge points including the La Rue Spring were measured. Shallow soil probe holes were drilled in the wetlands for preliminary evaluation of the distribution of the various types of surficial deposits. Aerial photographs, topographic maps, and soil maps were used as bases for field mapping of surficial deposits and for determining the boundaries and surface drainage characteristics of the study sites.

For detailed characterization of surficial deposits in the wetlands, thirty shallow bucket-auger borings were drilled along five transects oriented perpendicular to the long axis of each wetland swale. Samples taken at 15-centimeter (6-inch) intervals were examined in the field, and grain size, color, and structure were recorded. Each boring penetrated the entire thickness of the swale-fill sediments and the upper part of the underlying sandy deposits. After the distribution and thickness of the swale-fill deposits were determined, seven hollow-stem auger borings were drilled with a Mobile Drill, model B-30S. Shelby tubes were pushed to obtain undisturbed samples for laboratory determination of hydraulic conductivities. Additional bucket-auger borings were then drilled to install piezometers for measurement of water levels and determination of hydraulic gradients through the swale-fill sequence. Piezometers were installed using methods described by Luthin (1966).

In the laboratory, 5-centimeter (2-inch) cores were carefully extracted from the center of the 7.6-centimeter (3-inch) Shelby tube samples. These cores were saturated with water, and hydraulic conductivities were measured using the constant-head method described by Klute (1965).

The measurement of hydraulic conductivities of very fine-grained sediments presents some unique difficulties, and consequently engineering procedures for these measurements have not been standardized. The constant-head test and the swelling properties of clay samples from the wetlands both contribute to lower hydraulic conductivity measurements than probably exist in the field. Other physical properties of alluvial deposits of the Mississippi River which are of significance in understanding the ground-water system in wetlands are the drainable pore space fraction (f), the unsaturated hydraulic conductivity $K(\theta)$, and the volumetric water content (θ). At this time, the hydraulic conductivity (K) is the only physical property being evaluated. However, in any future detailed study of hydrogeology of wetlands, these additional physical properties of the alluvial sediments should be determined.

DISCUSSION

Hydrogeology of the La Rue Swamp

The La Rue Swamp is located adjacent to the eastern bluffs of the Mississippi Valley in the northeastern portion of the Big Five Drainage and Levee Districts (figure 1). The swamp occupies an abandoned meander belt of a former course of the Big Muddy River in Sections 9, 16, 21, and 28, T. 11 S., R. 3 W., Union County.

Ground-water contributions to the total water budget of the La Rue Swamp come from two sources: (1) discharge of water from the ground-water system in the alluvial deposits of the valley, and (2) discharge of water from the bedrock units that form the upland to the east of the swamp.

The principal factors that determine the contribution to the swamp of ground-water from the alluvium are the character of the alluvial deposits and the ground-water flow directions through those deposits. No specific information exists on either factor. Because the water-conducting properties of the alluvial deposits control ground-water flow into and seepage out of the swamp, this lack of information makes impossible any quantitative assessment of the role of alluvial ground water in the water budget of the swamp. A detailed field study involving well and piezometer installations and discharge measurements in bottom sediments would be required to make any assessment of the ground-water system in the alluvium.

The general vertical succession of deposits in the swamp may be similar to that encountered in a water well located just south of the swamp in the SE¼ NE¼ Section 33, T. 11 S., R. 3 W. The drillers log showed the following succession:

Unit	Thickness Meters	Thickness Feet
gray clay	3.0	(10)
brown silt	4.5	(15)
sand and gravel	9.0	(30)
sandy silt	3.0	(10)
sand and gravel	18.0	(58)
limestone	not penetrated	

The swamp is probably underlain by 30 to 40 meters (100 to 130 feet) of alluvium, the lower half of which is probably sand and gravel. The character of the upper portion is extremely complex because of reworking of sediments by the migration of the meandering Big Muddy River. The succession includes point bar, natural levee, channel fill and flood basin deposits from the Big Muddy, as well as, flood basin deposits from the Mississippi.

The first indication that ground water disharging from the upland bedrock units might be contributing to the swamp came when a small spring with an estimated discharge of about 20 liters per minute (5 gallons per minute) was observed flowing from a horizontal parting in cherty limestone at the base of the bluff in the SE corner of the SE¼ NW¼ SE¼ Section 9, T. 11 S., R. 3 W. (figure 2). This observation has lead to further field investigation designed to locate other points of discharge and to determine the source and significance of ground-water discharge from the bluff into the swamp.

Along the base of the bedrock bluff in the swamp area, there are a series of coalescing talus slopes and colluvial fans formed from rock-fall material and slopewash of loessial silt from the upland. The La Rue Spring occurs in one of the few places where the talus slope is absent, and the base of the bedrock bluff is exposed. This topographic setting is the principal factor making obvious the discharge of the spring. Talus slopes and colluvial fans elsewhere along the bluff probably obscure numerous other points of ground-water discharge. Along covered foot slopes, discharges would be diffuse and ground water would enter the swamp by seepage through bottom sediments. Most of the foot slope of the bluff is covered with talus debris. Consequently, more ground water is undoubtedly entering La Rue Swamp by seepage than by direct flow from the spring.

The geologic formations providing the source of the La Rue Spring and other seepage discharge are the Lower Devonian rocks of the Bailey, Grassy Knob, Backbone, and Clear Creek Formations that form the bedrock upland east of the swamp (figure 2). These units have been described by Weller and Ekblaw (1940) and Willman et al. (1975).

Bailey Limestone. The Bailey Limestone is the principal cliff-former in the Mississippi River bluff. The Bailey is a thin-bedded, very earthy and siliceous formation that contains much chert. The limestone is medium gray, dense or slightly shaly, and mostly occurs in beds less than 10 centimeters (4 inches) thick. It weathers to buff or gray, and much of it is so impure that when it is leached of its lime content, the strata are not reduced in thickness. Unweathered Bailey Limestone is well exposed in the Mississippi bluffs adjacent to the La Rue Swamp where sheer cliffs rise to a height of 30 meters (100 feet) or more. The formation may be more than 100 meters (328 feet) thick and extends well below the base of the bluff in the swamp region.

Grassy Knob Chert. The Grassy Knob Chert constitutes the lower part of the light-gray-to-white novaculitic chert succession that is the most prominent part of the Devonian System in southwestern Illinois. In the bluffs above Big Muddy River north of the La Rue Swamp, the transition from Bailey to Grassy Knob is well exposed. Bedded chert becomes more prominent and the interbedded layers of impure limestone become thinner. The Grassy Knob is about 60 meters (200 feet) thick in the region east of the swamp.

Backbone Limestone. The Backbone Limestone, which overlies the Grassy Knob Chert, consists of light gray massive crystalline limestone

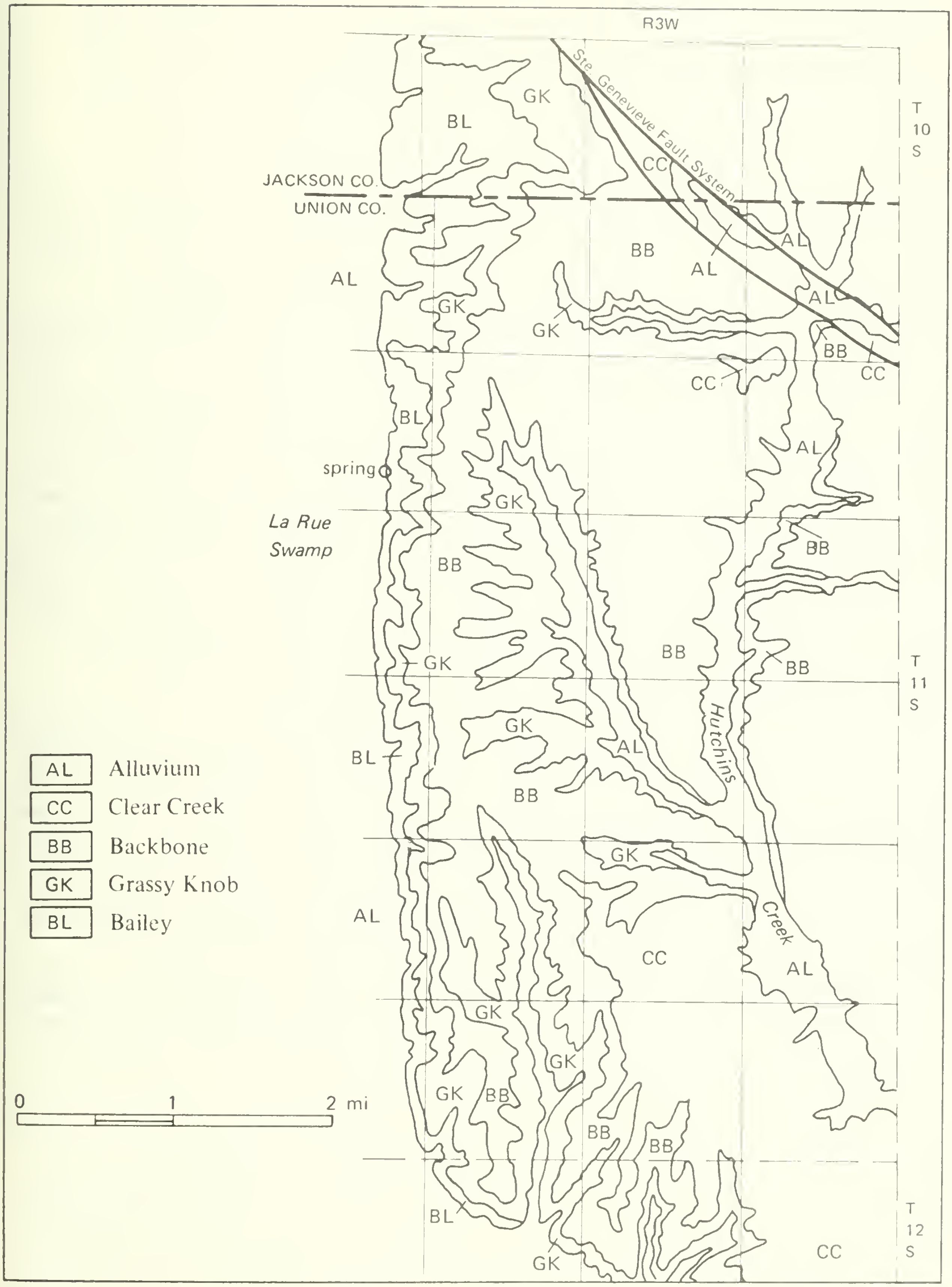


Figure 2. Bedrock geology of the La Rue Swamp area, northern Union County, Illinois (after Weller and Ekblaw, 1940)

with some chert beds. Chert content increases upward as the limestone loses much of its massive appearance. It commonly weathers to a rough surface upon which crinoid stem segments are conspicuous. In northern Union County the unit may attain a thickness of 60 meters (200 feet) or more. The Backbone Limestone overlies the Grassy Knob Chert, and caps the bluff above the La Rue Swamp.

Clear Creek Chert. The Clear Creek Chert overlies the Backbone Limestone, and consists principally of novaculitic chert, although fine-grained very siliceous limestone in variable amounts is present at many outcrops in northern Union County. Where the limestone has been removed by leaching, the chert has been left as an exceedingly rough, porous, vesicular mass. The thickness of the Clear Creek is difficult to determine, but is at least 90 meters (300 feet) in the outcrop area of Union County.

In the bluff exposures adjacent to the La Rue Swamp, the Lower Devonian strata are broken by common, nearly vertical joints that may significantly increase the capacity of the rock units to conduct water. No offsets of bedding that would indicate fault displacements along these fractures were observed during field examination for this study. However, large-scale faulting is associated with the Ste. Genevieve Fault Zone (Weller and Sutton, 1940) approximately 3 kilometers (1.9 miles) northeast of the La Rue Swamp (figure 2), and some faults may cut the upland bedrock sequence to the east of the swamp. Pryor (1956) indicated that the limestone and chert formations of the Devonian System in this area are well creviced and are good-to-excellent sources for domestic and farm water supplies.

A preliminary assessment of the significance of the contribution to the La Rue Swamp of ground-water seepage from the upland can be drawn from several field observations. The discharge from the La Rue Spring is small and apparently not flowing under significant pressure. This suggests that the spring is a discharge point where water table and ground surface meet. Observations of stream flow and seepage from alluvial gravels in Hutchins Creek and its tributaries indicate that Hutchins Creek about 3.5 kilometers (2.2 miles) east of the swamp is a major area of ground-water discharge and that the ground-water divide (a feature analogous to a surface drainage divide) between water flowing west to the swamp and that flowing east to the creek is probably about midway between the bluff and Hutchins Creek. The upland catchment area for ground water discharging into the swamp is the area between the divide and the bluff, an area approximately equal to the area of the swamp itself.

The topography of the upland catchment area is extremely rugged, and surface drainage for almost the entire area is easterly to Hutchins Creek. The ratio of surface runoff to ground-water recharge from a precipitation event in the rugged upland area is very large and most of the precipitation falling on the catchment area runs off to Hutchins Creek. On the other hand, runoff from the same precipitation falling on the swamp is nearly zero. Given the approximately equal areas of the ground-water catchment and the swamp, it is apparent that ground-water seepage from the upland can contribute only a small fraction of the volume of water that is contributed to the La Rue Swamp directly by precipitation.

Table 2. Temperature of the La Rue Spring discharge

Date	6/29	8/25	9/7
^{o}F	63^{o}	57^{o}	56^{o}

Temperature measurements of the La Rue Spring (table 2) indicate a seven-degree drop in temperature through the summer from late June to early September, a period when air temperatures are higher and when water seeping into the ground in the upland catchment area should have been warmest. The cooling trend through the summer months suggests the flow path of water discharging during that period was long enough for temperatures to exhibit an out-of-phase relation with average air temperature. Cool water that entered the ground-water system during a cool season was discharged during a warm season. Thus, the travel time from recharge to discharge is probably at least several months.

Hydrogeology of the Big Five North Wetland

A wetland, here referred to as the north wetland, occurs in an elongate swale about 3 kilometers (1.9 miles) south of Ware and about 1 kilometer (0.6 miles) west of Running Lake Ditch in the NW¼ Section 1 and the NE¼ Section 2, T. 13 S., R. 3 W. in the northern portion of the Big Five Districts in Union County (figure 1). Periodic examination of the north wetland by Corps and Survey personnel has shown that the wetland exhibits cyclic ponding and drying. A field examination of the site with exploratory drilling and instrumentation was conducted to establish the hydrogeologic conditions at the site and to determine the possible impact of proposed drainage improvements on the wetland.

The north wetland occurs in a ridge and swale complex approximately 2.5 kilometers (1.5 miles) east of the main channel of the Mississippi. It is situated in a low portion of the floodplain. The elevation of the center of the swale is about 101 meters (333 feet) above mean sea level, and the general elevation of the surrounding floodplain is above 104 meters (340 feet) and in places reaches 107 meters (350 feet).

The broad ridge and swale system in which the wetland occurs (figure 3) truncates the trend of the channel-fill deposits in the Grassy Lake meander to the east. Running Lake Ditch extends along the east margin of this ridge and swale system. Several other ridge and swale complexes are found within the region shown in figure 3, and the margins of these ridge and swale systems are usually bounded by natural levee deposits. Within the north wetland study area in the center of figure 3,

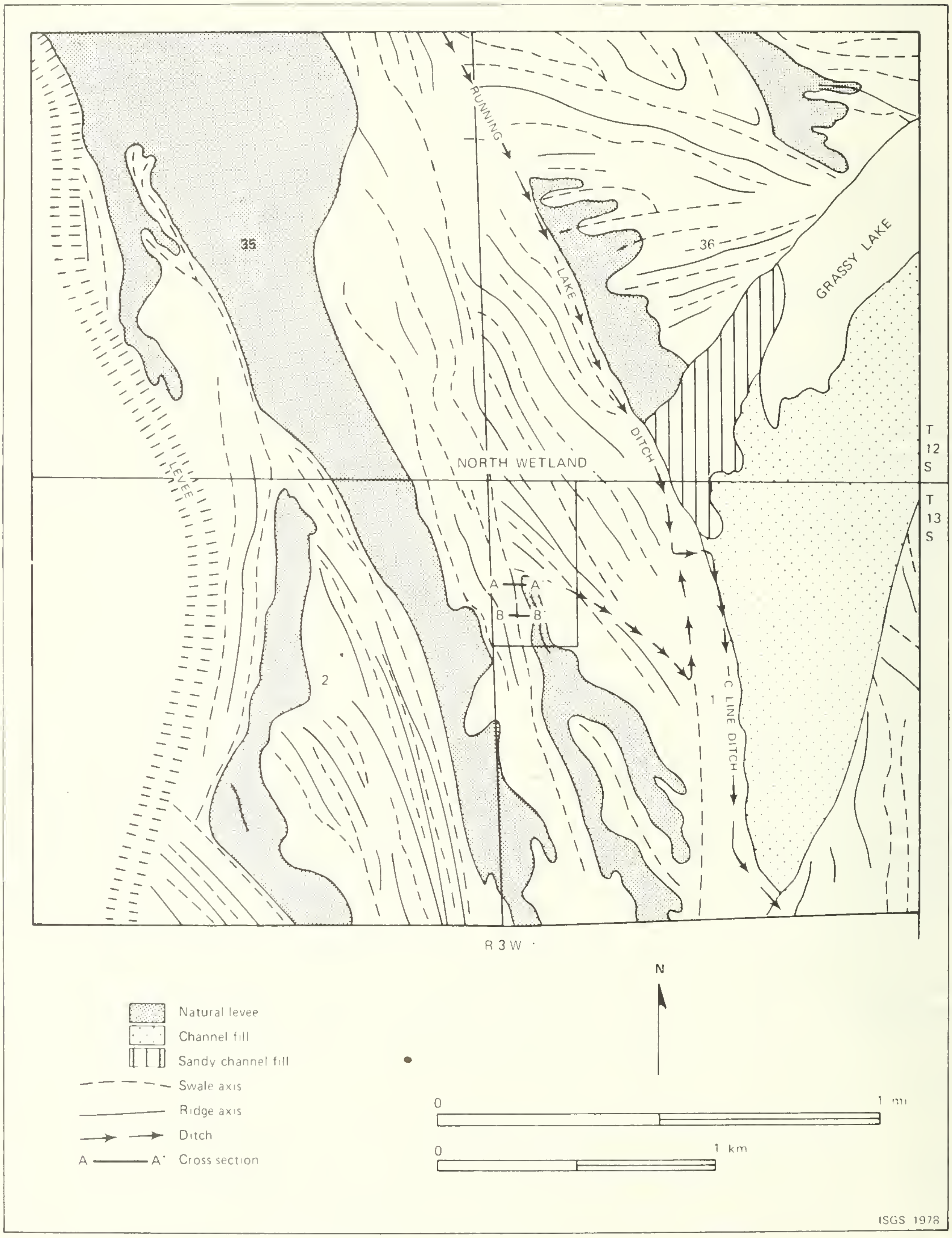


Figure 3. Physiographic features in the vicinity of the north wetland

a northwest-southeast trending ridge and swale system in the eastern half of the area is truncated by the more north-south trend of a younger ridge and swale in the western half. The long continuous north-south swale in the center of the area is the major feature studied and the easternmost swale of the north-south ridge and swale system. A small natural levee occurs adjacent to this swale in the central and southern portion of the study area.

Sixteen borings were drilled in the swale to characterize the distribution of geologic materials across the landscape and in the shallow subsurface below the wetland (figure 4). Two cross sections, A-A' and B-B' (figure 5), show the complexity of the stratigraphy. Six lithologically distinct units were described (table 3) and traced in the north wetland. The distribution and character of these materials in the wetland area reveal the origin of the succession, and identify the constraints that the succession places on ground-water flow.

The geologic materials encountered in the subsurface include channel, channel-fill, swale-fill and natural levee deposits. Units I and II are part of an old floodplain succession found in the northwest-southeast trending ridge and swale of the eastern portion of the north wetland study area. Unit I represents channel or point bar deposits of the channel that migrated eastward and truncated the trend of the Grassy Lake meander. Regional data suggest that Unit I is continuous with deep sands that underlie the entire floodplain. Unit II consists of a topstratum or overbank sediments deposited on the old point bar. Units III and IV were deposited by a later phase of meander migration when the north-south trending ridge and swale truncated the older deposits. Unit III includes natural levee sands and silts deposited on top of the older floodplain when a channel or chute of the Mississippi occupied the position of the north wetland swale. Unit IV is fine channel sand, some of which may have been deposited after the channel or chute was cut off from the main channel. Units V and VI are swale-fill or channel-fill sediments that postdate channel cutoff. Unit V is silty and is coarser than Unit VI. This textural difference suggests that, through time, the velocity of water flowing through the swale has decreased and/or that the source of the sediment has, with channel migration, become more distant. Completion of cutoff of the north wetland from the main channel and migration of the channel to the west margin of the valley allowed only fine silty clays, Unit VI, to be transported into the wetland by flood waters. These fine-textured sediments have accumulated intermittently, burying soil horizons that mark briefly stable land surfaces. These soils are shown in section B-B' (figure 5).

To understand the contribution that ground-water movement through the clay-rich swale-fill deposits makes to the total water budget of an alluvial wetland, the quantity of water that can move through the swale fill per unit time must be determined. This quantity, referred to as the discharge (Q), is controlled by the hydraulic conductivity (K) of the deposits, by the hydraulic gradient (∇H) or head loss through the deposits, and by the area (A) of the wetland. Discharge (Q) is calculated using the

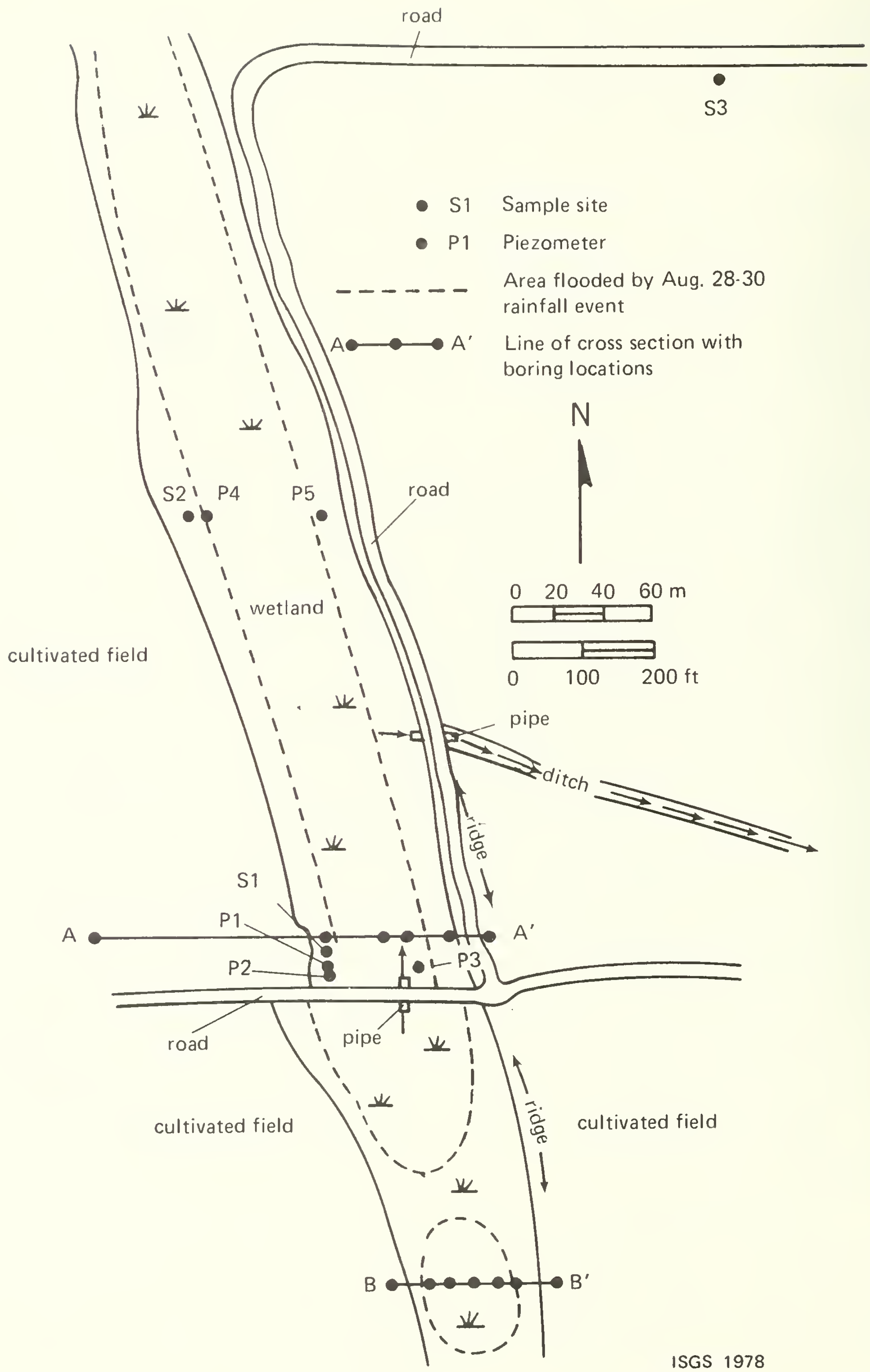


Figure 4. Locations of cross sections, borings, and piezometers in the north wetland

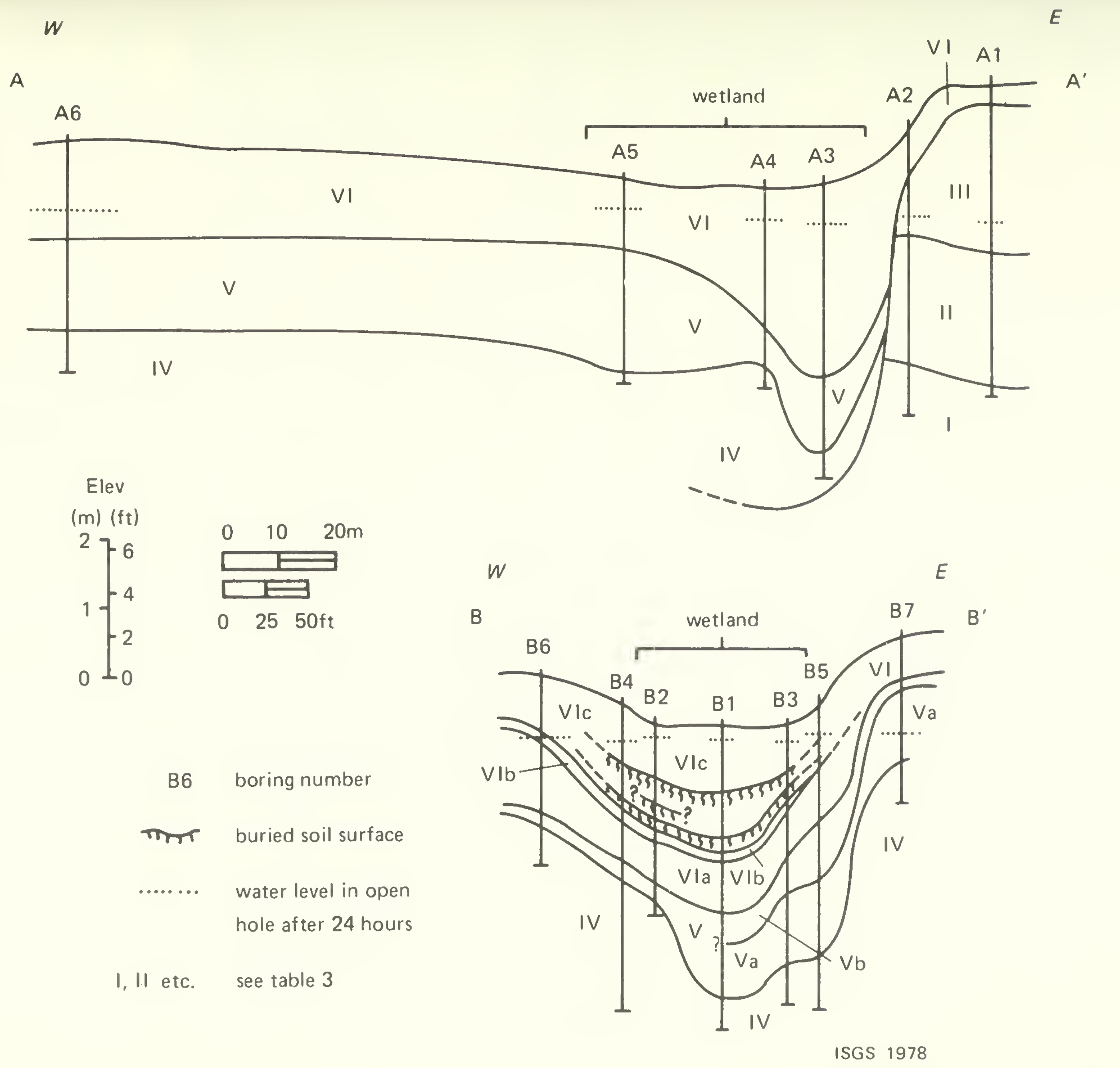


Figure 5. Cross sections of the north wetland

Table 3. Descriptions of geologic materials from borings in the north wetland

Unit	Description
I	Sand, fine with some medium, gray, clean, includes some zones of silt or loamy sand; channel deposits.
II	Silty clay, gray to brown, with silty clay loam and silt loam strata; decreases in clay content upward; overbank floodplain deposits.
III	Sand, fine, grading into sandy loam, silt loam and loam, brown; natural levee deposits.
IV	Sand, fine and very fine, gray, includes some loamy very fine sand; channel deposits.
V, Va, Vb	Silty clay loam and silt loam, gray to brown stratified sediments increase in clay content upward; separated into Va (silt loam) and Vb (silty clay loam) in part of transect B-B'; channel-fill deposits and swale-fill deposits.
VI, VIa, VIb, VIc	Silty clay, brown, occasionally gray at base, uniform, firm, sticky. In transect B-B', VIa (silty clay) is separated from VIc (silty clay) by a 15 cm thick silt or silt loam (VIb). Within VIc are two or three buried soil surfaces indicated by dark gray to black humus zones. The upper zone in boring B3 contains wood fragments. Channel fill and swale fill deposits.

equation

$$Q = K \nabla H A \qquad (3)$$

The direction of water movement is controlled by the hydraulic gradient. Water movement can be either upward or downward through the swale-fill deposits and is either a positive or negative factor in the overall water budget. With upward movement, ground water is an input or positive contribution to the water budget of the wetland. Downward movements are negative factors or outputs in the budget, as water is recharged into the ground-water system. Temporal changes in hydraulic gradient can be dramatic, and may cause complete reversal of flow direction. To fully understand the ground-water factor or any of the other factors (precipitation, runoff, evapotranspiration) in a water budget, long-term monitoring through seasonal cycles must be undertaken.

Changes in the hydraulic gradient can be induced by ditching or drainage improvements. Ditching may lower water levels in the sandy channel or channel-fill sediments beneath the wetland, increasing the downward hydraulic gradient. The effect that the increase in gradient has on the water budget of the wetland depends entirely on the hydraulic conductivity of the swale-fill sediments. Very tight, clay-rich, deposits with very low hydraulic conductivities will yield only slightly increased quantities of water in response to large increases in gradient. The increase in discharge (Q) induced by drainage or partial drainage of the sandy materials may, on the other hand, be large if the bottom sediments in the wetland are moderately permeable.

To characterize ground-water flow in the immediate vicinity of the swale, five piezometers (P1 through P5 on figure 4) were installed. The four deep piezometers (P1, P3, P4, and P5) at the corners of the roughly rectangular array have 0.6-meter (2-foot) screens installed in the upper part of the Unit IV sands. Comparison of pressures measured in these piezometers allows calculation of horizontal pressure gradients and determination of flow directions in the sand units. Comparison of pressures between the screens of piezometers P1 and P2, P2 installed in the silt loam and silty clay loam of Unit V and the adjacent P1 in the sand, allows calculation of vertical gradients in the swale fill and determination of flow direction, upward or downward.

Piezometer records and other data required for calculation of hydraulic gradients are shown in Table 4. These data indicate that on September 6, 1978, the ground water was moving upward toward the wetland surface (discharging to the wetland) with a gradient approximately equal to 0.11. However, on November 17, 1978, the ground water was moving downward (discharging from the wetland) with a gradient of 0.04.

To estimate the volume of water of ground-water contribution to or loss from the wetland, the hydraulic conductivities and gradients of the swale-fill sequence should be evaluated. Table 5 shows the results of the laboratory analyses of the Shelby tube samples.

Table 4. Elevation and water level data for north wetland piezometers

	Piezometers					Surface-water levels
	P1	P2	P3	P4	P5	
Ground surface elevation	101.74m (333.78ft)	101.74 (333.78)	101.62 (333.39)	101.64 (333.47)	101.43 (332.78)	
Screen elevation	98.38 (322.78)	100.37 (329.28)	97.96 (321.39)	99.20 (325.47)	97.77 (320.78)	
Water level 9/6/78	101.15 (331.86)	100.93 (331.11)	101.21 (332.05)	101.26 (322.21)	101.26 (332.21)	not measured
Water level 11/17/78	101.00 (331.36)	101.08 (331.62)	100.87 (330.93)	101.16 (331.89)	100.90 (331.03)	101.58 (333.26)

Table 5. Hydraulic conductivity values of selected soil samples from the north wetland

Boring * number	Depth cm	Depth ft	Average hydraulic conductivity (cm/sec)	Unit	Texture
SI	30-60	1-2	8.1×10^{-8}	VI	silty clay
	90-120	3-4	3.5×10^{-6}	V	silty clay loam
	460-503	15-16½	5.7×10^{-5}	IV	fine sand
S2	30-60	1-2	2.5×10^{-8}	VI	silty clay
	90-120	3-4	2.3×10^{-6}	V	silty clay loam
	427-503	14-16½	5.7×10^{-5}	IV	fine sand
S3	610-655	20-21½	6.2×10^{-4}	IV or I	fine sand
	914-960	30-31½	3.0×10^{-5}		

* see figure 4.

The hydraulic conductivity value of each soil layer is the average of multiple determinations on triplicate samples from that layer. Silty clays of unit VI have an average hydraulic conductivity (K) of about 5×10^{-8} cm/sec (1.4×10^{-4} ft/day). In comparison, the silty clay loams of unit V and the sands of units IV and I have K values of about 3×10^{-6} cm/sec (8.5×10^{-3} ft/day) and about 5×10^{-5} cm/sec (1.4×10^{-1} ft/day), respectively.

Assuming that (1) ground water is flowing through the swale-fill sediments under steady-state conditions, (2) the upward hydraulic gradient (September 6 measurement) is about 0.11, and (3) the average hydraulic conductivity is 3.5×10^{-6} cm/sec (1.0×10^{-2} ft/day), discharge can be calculated. Under these conditions, daily upward flow of ground water into the wetland amounts to about 3.3 m^3 (870 gallons) through each hectare (2.47 acres) of surface area.

On November 11, 1978, ground-water flow in the north wetland was downward with a gradient of 0.04. Under these conditions, one hectare (2.47 acres) of the wetland would lose about 1.2 m^3 (320 gallons) daily to the ground-water aquifer. For comparison, the volume of water in a 2.5 centimeter (1 inch) rainfall on a one hectare (2.47 acres) area is over 250 m^3 (66,000 gallons).

These data alone are not sufficient to allow an assessment of the role of ground water in the budget of the wetland. They give the magnitude of water movement on two different dates, but rather than allowing specific statements, they force generalization by emphasizing the temporal variability of the system. The extent to which measured variations in hydraulic gradient are controlled by regional or by local factors cannot be evaluated with existing data. The relative importance of the river stage and ditch in determining the measured gradients is not known. It is likely that a change in the surface drainage system will alter the ground-water system, and that these alterations will be larger in areas close to the ditching system than in areas further away. However, the magnitude of the change at a given distance is at present not calculable.

Field observations and discussions with landowners have yielded insights into the frequency of flooding and sources of water that periodically flood the north wetland. Landowners have indicated that principal sources of water are precipitation and backflow from Running Lake ditch. Precipitation, after filling the center of the wetland to a depth of about 30 centimeters (1 foot), drains rapidly into Running Lake ditch when the water level of the ditch is low. Drainage occurs through an easterly flowing ditch connected with the swale by a pipe beneath the road that parallels the east side of the swale (figure 4). This ditch is periodically cleaned out by the landowners. A pipe beneath the road crossing the south-central portion of the swale (figure 4) connects the north and south swale segments. During a 13 cm (5 in.) rainfall event that occurred August 28 through 30, the swale, which had been dry since late June, was flooded. The extent of flooding, shown in figure 4, was insufficient to raise water levels to the height required for surface runoff to Running Lake ditch.

By September 7, eight days after the rain, shallow water remained standing in some small depressional areas in the swale, but evapotranspiration and infiltration had dried the wetland sufficiently to allow drilling equipment access along the margins of the swale.

Landowners stated that the most extensive flooding of the wetland occurs when high water levels in Running Lake ditch back up into the swale. The swale and much of the surrounding farmland are inundated during spring months by this backflow. High water remains in the swale until water levels in the ditches fall enough to allow surface drainage. Any drainage improvement that lowers the peak flow and decreases the duration of high water levels in Running Lake ditch will lower the water depth and decrease the duration of flooding in the wetland and surrounding cultivated land. Landowners stated that in the past the swale has been too wet to farm 90 percent of the time, and that water standing on surrounding land has frequently delayed spring planting.

Hydrogeology of the Big Five South Wetland

A wetland, here referred to as the south wetland, occurs in a broad swale about 2 km (1.25 miles) south of Highway 146, 1.4 km (.85 miles) west of Highway 3, and 1 km (.6 miles) west of East Cape Main ditch in the NW¼ Section 29, T. 14 S., R. 3 W. in the southern portion of the Big Five Districts in Alexander County (figure 1). Periodic examination of the south wetland has shown that, like the north wetland, it exhibits wet and dry cycles. An exploratory drilling and instrumentation program in the south wetland was conducted to establish the hydrogeologic conditions at the site and to determine the possible impacts of proposed drainage improvements.

The south wetland occupies a broad swale in a generally northwest-southeast oriented ridge and swale complex (figure 6) and is located about 2.4 km (1.5 miles) northeast of the main channel of the Mississippi. The northern boundary of the study area is paralleled by a ditch, and the wetland and adjacent swales are drained to the southeast by small ditches which empty into the East Cape Main ditch in the southeast corner of Section 29 (figure 6). The south wetland swale, the westernmost swale in the study area (figure 6), has an elevation of about 99.4 meters (326 feet) in its center, somewhat lower than the north wetland and lower than the surrounding floodplain, which averages about 102.1 meters (335 feet) and exceeds 103.6 meters (340 feet) in some places.

The local physiographic setting in the south wetland area is less diverse than the north wetland area. The south wetland occurs in a large ridge and swale complex extending from the eastern bluff of the valley to the main channel at Cape Girardeau. There are no large natural levee systems like those found further north. The ridge and swale complex is a large scale point bar that was deposited as the main channel migrated from east to west across the area.

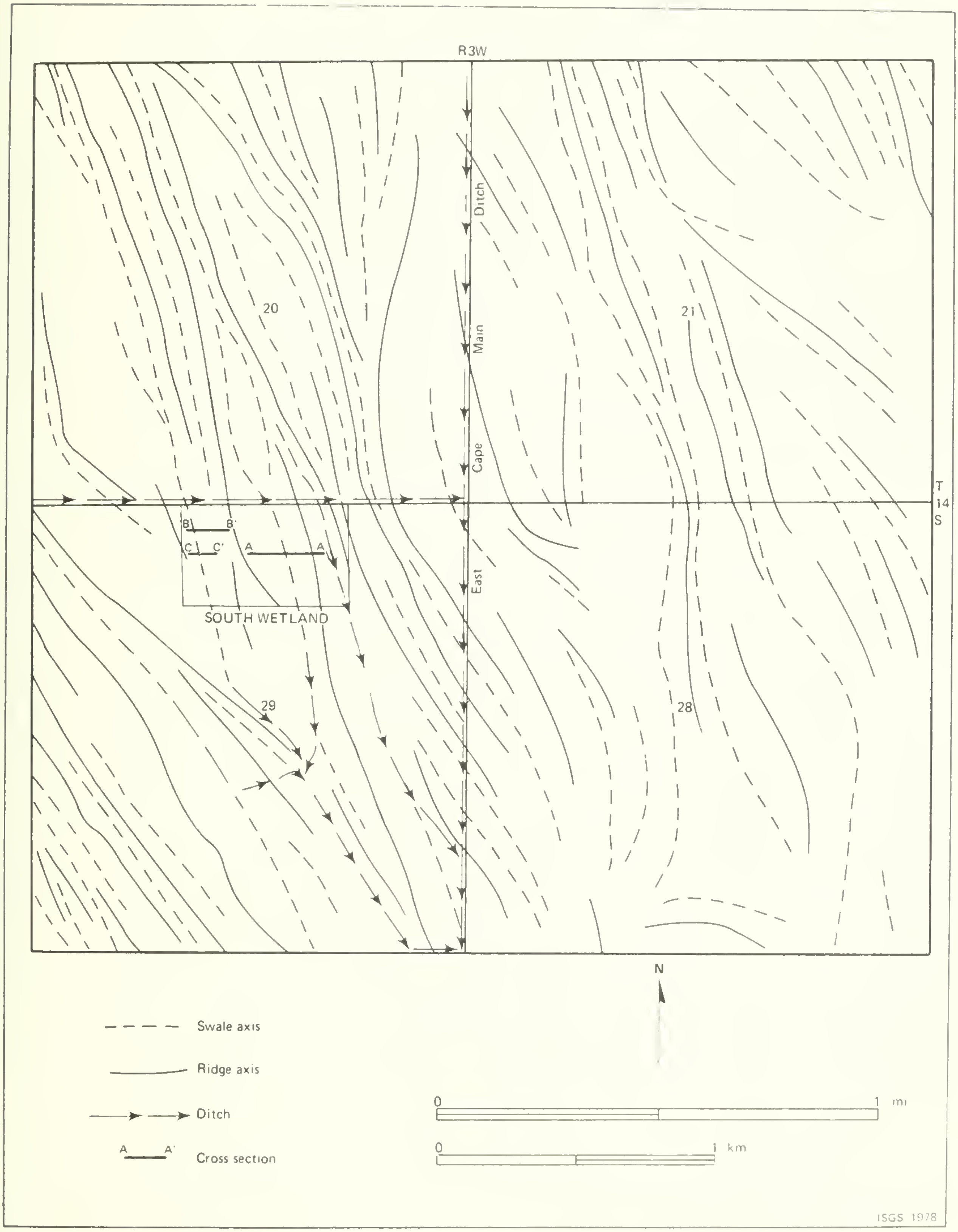


Figure 6. Physiographic features in the vicinity of the south wetland

Twenty-one borings were drilled in the south wetland and adjacent swales to characterize the distribution of geologic materials across the landscape and in the shallow subsurface (figure 7). Three cross sections, A-A', B-B', and C-C', (figure 8), show the distribution of alluvial deposits across the area. Four lithologically distinct units were described and traced in the subsurface (table 6).

Units I and II are sandy channel deposits that are similar to Units I and IV of the north wetland. Unit II is finer and contains more fine strata than Unit I. The swale-fill succession, Unit III, of the south wetland is thinner and less complex than the swale fill of the north wetland. Unit III reaches a maximum thickness of 2.2 meters (7.2 feet) and is mostly massive silty clay with strata of silty material in its lower part. No buried soil horizons were identified. Cross section A-A' (figure 8) shows that unit III is continuous across several ridges and swales to the east of the principal study site. The western end of section B-B' encountered natural levee sediments, Unit IV, on the west ridge.

To characterize ground-water flow in the immediate vicinity of the wetland, five piezometers (P1 through P5 on figure 7) were installed. Four deep piezometers (P1, P2, P3, and P5) at the corners of the array have 0.6 meter (2 foot) long screens installed in the upper part of the unit I and II sands for determination of horizontal pressure gradients and flow directions. Comparison of pressure readings from P3 in the sand and P4 in the shallow silty clay strata of unit III allows determination of vertical gradients and flow directions in the swale fill.

Piezometer readings and other data required for the calculation of hydraulic gradients are shown in table 7. These data indicate that on September 5, and November 17, 1978, the downward hydraulic gradients had values of 0.14 and 0.27, respectively. Table 8 shows the result of the laboratory determination of selected soil samples of the swale-fill sucessions. The values obtained for these samples are similar to those in the north wetland (table 5). Notice that the silty clay of unit III (S1, 0-15 cm and S2, 30-90 cm) has a very low hydraulic conductivity in comparison to the sandy layer (S1, 450-495 cm and S2, 270-345 cm). This unit acts as the principal barrier between surface and ground water.

Discharges on a daily basis through the swale-fill materials under the downward gradients measured on September 5, and November 17, 1978, were 4.5 m^3 (1200 gallons) and 8.8 m^3 (2300 gallons) respectively, through each hectare (2.47 acres). These volumes were somewhat larger than those calculated for the north wetland, because south wetland gradients were higher.

As with the north wetland, data are inadequate to permit quantitative analysis of either the role of ground water in the budget of the south wetland or the changes in that role that might be induced by alteration of surface drainage. However, preliminary data from deep piezometers in the south wetland suggest that water levels in the sands of units I and II are quite responsive to levels in the ditch along the northern edge of the wetland.

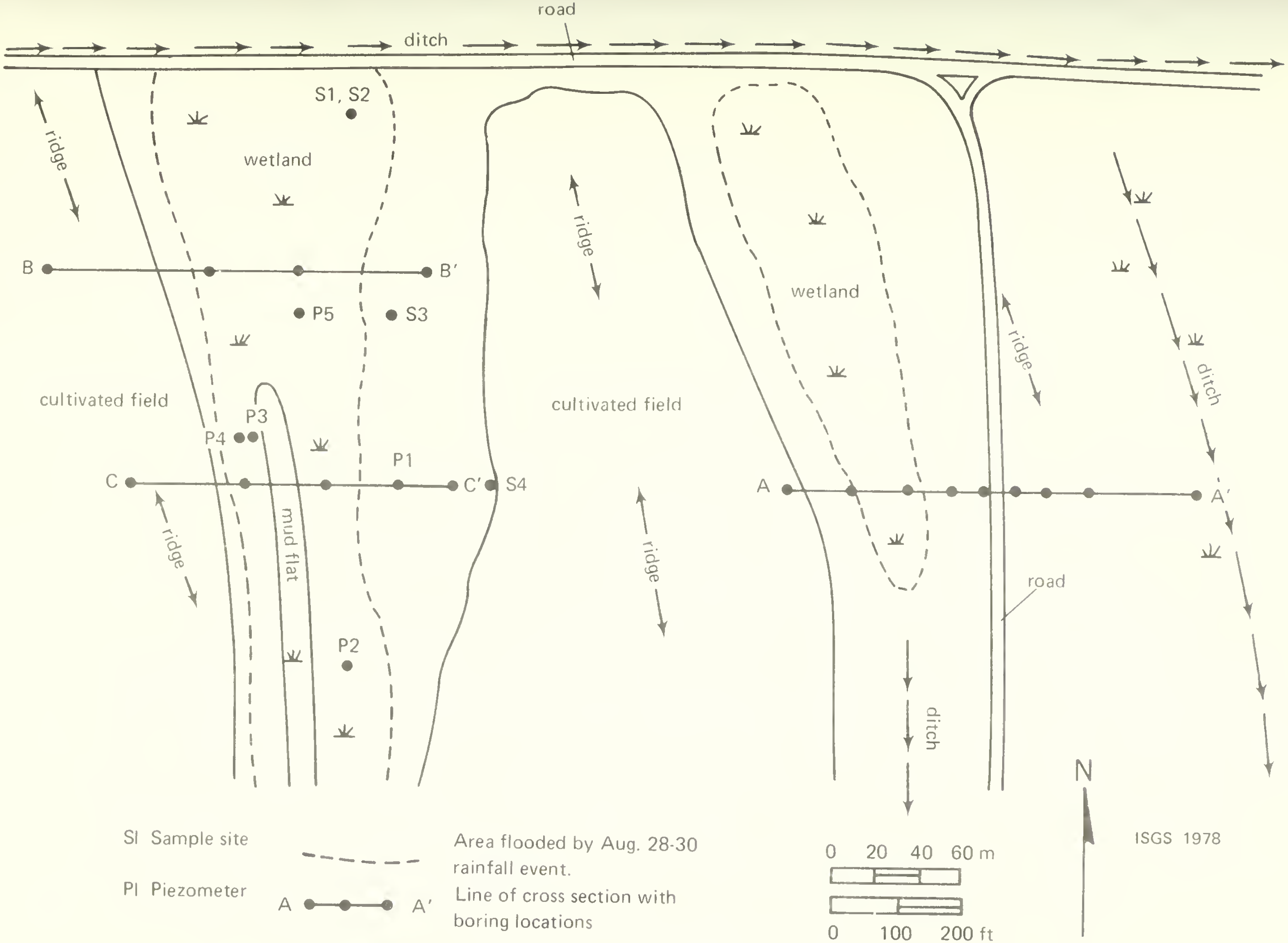


Figure 7. Locations of cross sections, borings, and piezometers in the south wetland

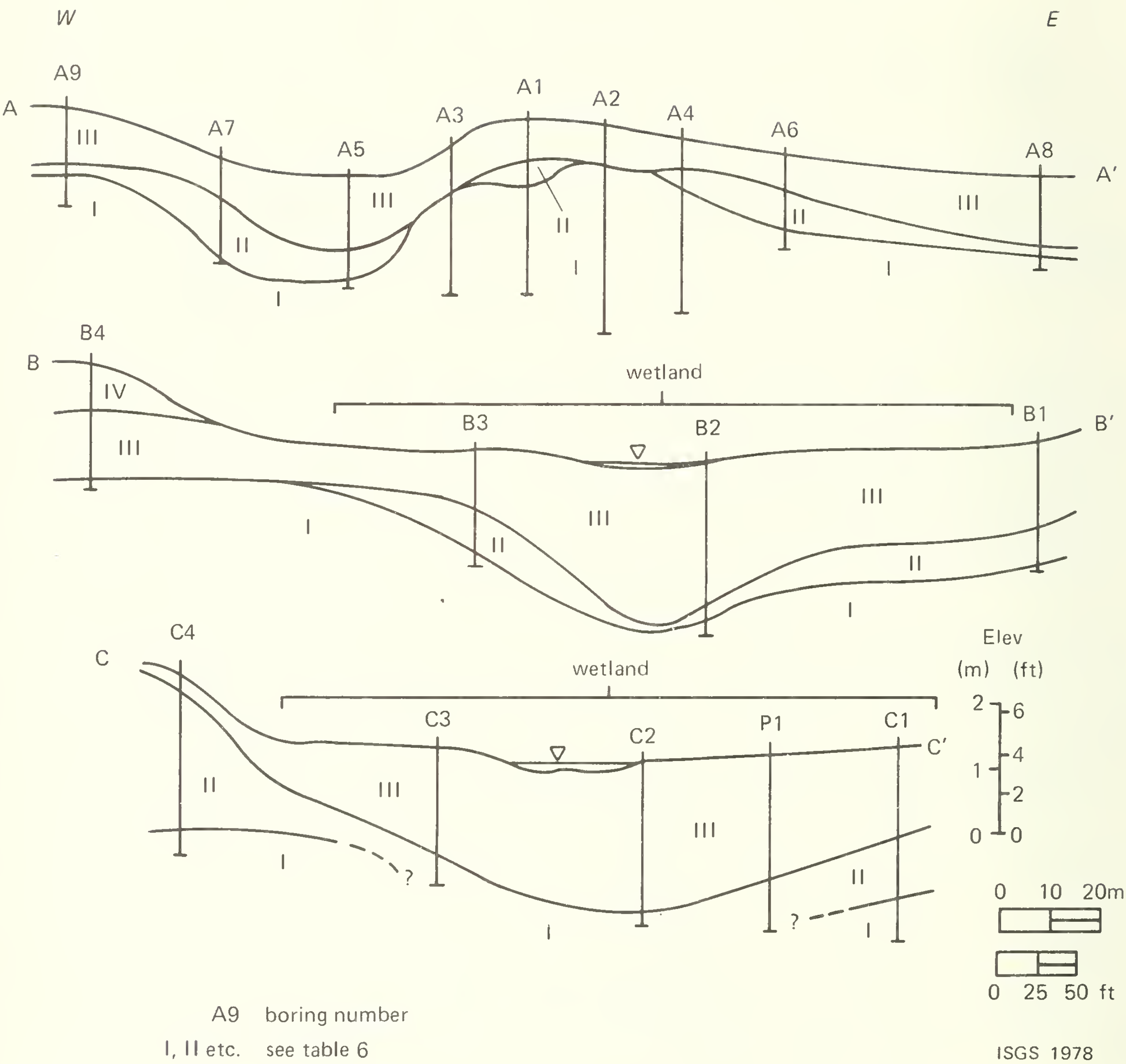


Figure 8. Cross sections of the south wetland

Table 6. Descriptions of geologic materials from borings in the south wetland and adjacent swales

Unit	Description
I	Sand, fine to medium, gray or brown, well-sorted, includes some zones of loamy sand and silt loam; <u>channel deposits</u>.
II	Sand, fine to very fine, gray or brown, poorly sorted, includes common strata of sandy loam and silt loam; <u>channel or channel-fill deposits</u>.
III	Silty clay, gray and brown, uniform, sticky, firm. Contains occasional zones with plant debris. May show stratification in lower part; <u>swale-fill deposits</u>.
IV	Silt, silt loam, and sandy loam, brown, soft, stratified; <u>natural levee deposits</u>.

Table 7. Elevation and water level data for south wetland piezometers

	Piezometers					Surface water levels
	P1	P2	P3	P4	P5	
Ground surface elevation	100.20m (328.74ft)	99.71 (327.12)	99.49 (326.42)	99.49 (326.42)	99.63 (326.86)	
Screen elevation	97.61 (320.24)	97.73 (320.62)	97.67 (320.42)	98.58 (323.42)	97.04 (318.36)	
Water level 9/5/78	99.39 (326.07)	99.42 (326.17)	99.41 (326.16)	99.54 (326.58)	99.45 (326.27)	not measured
Water level 11/17/78	99.29 (325.75)	99.22 (325.52)	99.31 (325.82)	99.56 (326.64)	99.29 (325.75)	99.67 (327.00)

Table 8. Hydraulic conductivity values of selected soil samples from the south wetland

Boring * number	Depth cm	Depth ft	Average hydraulic conductivity (cm/sec)	Unit	Texture
SI	0-15	0-0.5	8.1×10^{-8}	III (upper)	silty clay
	30-60	1-2	3.5×10^{-6}	III (lower)	silty clay loam
	450-495	15-16½	5.7×10^{-5}	I, II	fine sand
S2	30-90	1-3	2.5×10^{-8}	III (upper)	silty clay
	135-210	4½-7	2.3×10^{-6}	III (lower	silty clay loam
	270-345	9-11½	5.7×10^{-5}	I, II	fine sand

* see figure 7.

The owner of the south wetland swale has indicated that the principal mechanism for extensive flooding in the area is backflow from East Cape Main ditch when gravity drains through the levee are closed. When the gravity drain is open, water exits the swale via the ditches.

The 13-cm (5 inch) rainfall of August 28 to 30 flooded the swales to approximately the extent shown in figure 7. By September 7, eight days after the rain ceased, the water had receded significantly, but the area that had been a mud flat prior to the rain was covered by about 0.5 meters (1.6 feet) of water. Standing water which had covered the S1 and S2 sampling sites to a depth of .15 meters (0.5 feet) during the rainfall had receded, but the ground remained saturated.

Precipitation, surface runoff, and backflow through drainage ditches are important factors in the water budget of the south wetland. It is apparent that drainage improvements that alter surface runoff characteristics may directly affect the volume of water in the wetland or the length of time that water stands in the swale.

CONCLUSIONS

The La Rue Swamp occupies an abandoned meander belt of a former course of the Big Muddy River. Ground-water input into the swamp comes from the alluvium and from the bedrock upland east of the swamp. The alluvial ground-water system is poorly documented, and further study is required for any assessment of its role in the water budget of the swamp. Ground-water discharge from the bedrock is visible at only one site, the La Rue Spring. The Lower Devonian limestones and cherts of the Bailey, Grassy Knob, and Backbone Formations are the principal source rocks for the spring discharge. Though the spring is the only visible discharge, ground water undoubtedly enters the swamp by seepage through talus slopes and alluvial sediments along most of the bluff. The volume of water annually entering the swamp by discharge from the bedrock is probably quite large; however, preliminary indications are that that volume is small in relation to the volume of water directly contributed to the swamp as precipitation.

The north and south wetlands occur in elongate swales in a relatively young portion of the Mississippi floodplain. Beneath each wetland surface is a 2-to-4 meter (6.1 to 12.2 feet) thick sequence of fine-textured, stratified, swale-fill sediments that overlies coarser-textured channel and point bar sands. Ground-water levels in the sandy units are controlled by both regional factors such as river stage and local factors such as ditching. Long-term monitoring and additional piezometer installations will be required for quantification of these factors. Ditching will alter the ground-water flow system locally, but the lateral extent of that effect is uncertain. If water levels in the wetland sand units are affected by ditching, hydraulic gradients through the overlying fine-textured swale-fill sediments will be changed, as will the volumes of water moving through the swale fill. If ditching results

in lower water levels in the sand units, there will be a net loss of water from the wetland. The magnitude of the potential change cannot be predicted without long-term collection of data on the contributions of the precipitation, surface runoff, and evapotranspiration factors of the water budget. However, the effect of even a small change in the ground-water system may be dramatic in terms of wetland permanence.

One readily apparent effect that proposed drainage improvements, especially pump installation, will have on the wetlands, is a reduction in the volume of flood water and the time that flood waters are retained in the wetlands. Waters that have in the past been retained inside the levee, flooding many wetland areas during periods of high river stage, will be more quickly drained from the wetlands by pumping.

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APPENDIX A

Logs of borings

NORTH WETLAND

Boring A1

Material*	Thickness, cm	(ft)
silt, friable	30	(1.0)
loam	15	(0.5)
silty clay loam	45	(1.5)
sandy laom	30	(1.0)
silt loam	15	(0.5)
medium to fine sand	75	(2.5)
silty clay loam	30	(1.0)
silt loam	30	(1.0)
silty clay loam	30	(1.0)
silty clay	90	(3.0)
silt loam	15	(0.5)
Loamy fine sand	15	(0.5)
TOTAL	420	(14.0)

Boring A2

Material	Thickness, cm	(ft)
silty clay	30	(1.0)
clay loam	30	(1.0)
loamy fine sand	60	(2.0)
silt loam	15	(0.5)
loam	15	(0.5)
silty clay	15	(0.5)
silty clay loam	60	(2.0)
silty clay	30	(1.0)
silty clay and silt loam strata	30	(1.0)
silty clay to clay, gray	45	(1.5)
loamy medium sand	15	(0.5)
silt loam	30	(1.0)
clean fine sand, gray	30	(1.0)
TOTAL	405	(13.5)

Boring A3

Material	Thickness, cm	(ft)
silty clay	285	(9.5)
silt loam	15	(0.5)
sandy loam	15	(0.5)
silty clay loam	75	(2.5)
very fine sand, clean	30	(1.0)
TOTAL	420	(14.0)

Boring A4

Material	Thickness, cm	(ft)
silty clay	195	(6.5)
silty clay loam	45	(1.5)
silt loam	15	(0.5)
very fine sand	15	(0.5)
TOTAL	270	(9.0)

Boring A5

Material	Thickness, cm	(ft)
silty clay	100	(3.3)
silt loam	5	(0.2)
silty clay with silt loam strata	170	(5.7)
fine sandy loam	15	(0.5)
TOTAL	290	(9.7)

Boring A6

Material	Thickness, cm	(ft)
silty clay	135	(4.5)
silty clay loam	45	(1.5)
silt loam	15	(0.5)
sandy loam	45	(1.0
silt loam	30	(1.0)
medium to fine sand	60	(2.0)
TOTAL	330	(11.0)

Boring B1

Material	Thickness, cm	(ft)
silty clay, dark zones at 90-105 and 150-165 cm	180	(6.0)
silt loam	15	(0.5)
silty clay	75	(2.5)
silty clay with silt loam strata	120	(4.0)
very fine sand, soft	45	(1.5)
TOTAL	435	(14.5)

*Textural designations follow guidelines of Soil Survey Staff (1975)

NORTH WETLAND (continued)

Boring B2

Material	Thickness, cm	(ft)
silty clay with dark zones at 75-90, 115-120, and 135-150 cm; silt loam stratum at 110 cm	150	(5.0)
silt loam	15	(0.5)
silty clay	60	(2.0)
coarse silt	15	(0.5)
silty clay, very sticky	15	(0.5)
Loamy very fine sand	15	(0.5)
TOTAL	270	(9.0)

Boring B3

Material	Thickness, cm	(ft)
silty clay, wood at 60 cm; dark zone at 90 cm	105	(3.5)
silt loam, light gray	15	(0.5)
silty clay; dark gray at 152 cm	60	(2.0)
silty clay loam	60	(2.0)
silt loam	105	(3.5)
very fine sand	60	(2.0)
TOTAL	405	(13.5)

Boring B4

Material	Thickness, cm	(ft)
silty clay with dark zones at 90-105 and 135-150 cm	150	(5.0)
silty clay loam	15	(0.5)
silty clay	60	(2.0)
silt loam, gray	15	(0.5)
silty clay, gray with brown mottles	15	(0.5)
loamy very fine sand, gray	60	(2.0)
silty clay, gray with brown mottles	15	(0.5)
silt loam with silty clay loam strata, gray	75	(2.5)

Boring B4 (continued)

Material	Thickness, cm	(ft)
fine to medium sand, clean, friable, gray	30	(1.0)
TOTAL	285	(9.5)

Boring B5

Material	Thickness, cm	(ft)
silty clay with silt loam stratum at 90 cm	165	(5.5)
silty clay loam	90	(3.0)
silt loam	30	(1.0)
silty clay loam	15	(0.5)
silt loam	15	(0.5)
loam	15	(0.5)
silt loam	30	(1.0)
loamy fine sand	15	(0.5)
sandy loam	15	(0.5)
medium sand	45	(1.5)
TOTAL	435	(14.5)

Boring B6

Material	Thickness, cm	(ft)
silty clay	75	(2.5)
silt loam	15	(0.5)
silty clay with silt loam strata	105	(3.5)
silt loam	15	(0.5)
loamy fine sand	60	(2.0)
TOTAL	270	(9.0)

Boring B7

Material	Thickness, cm	(ft)
silty clay	60	(2.0)
silty clay loam	15	(0.5)
silt loam	90	(3.0)
silty clay	15	(0.5)
loamy sand	15	(0.5)
medium and fine sand	45	(1.5)
TOTAL	240	(8.0)

SOUTH WETLAND

Boring A1

Material	Thickness, cm	(ft)
silty clay, heavy	60	(2.0)
loam	45	(1.5)
fine to medium sand	30	(1.0)
loamy fine sand	60	(2.0)
sandy loam	75	(2.5)
TOTAL	270	(9.0)

Boring A2

Material	Thickness, cm	(ft)
silty clay	60	(2.0)
fine sand	90	(3.0)
sandy loam to loamy sand	140	(4.7)
fine and medium sand	30	(1.0)
TOTAL	320	(10.7)

Boring A3

Material	Thickness, cm	(ft)
silty clay	75	(2.5)
loamy sand	135	(4.5)
silt loam	15	(0.5)
TOTAL	225	(7.5)

Boring A4

Material	Thickness, cm	(ft)
silty clay	50	(1.6)
sandy loam	30	(1.0)
loamy very fine sand	60	(2.0)
loam to silt loam	30	(1.0)
loamy very fine sand	30	(1.0)
silt loam	15	(0.5)
loamy very fine sand	30	(1.0)
fine sand, dirty	30	(1.0)
TOTAL	275	(9.1)

Boring A5

Material	Thickness, cm	(ft)
silty clay	120	(4.0)
clay loam to silty clay loam	45	(1.5)
medium to fine sand, clean	15	(0.5)
TOTAL	180	(6.0)

Boring A6

Material	Thickness, cm	(ft)
silty clay	50	(1.7)
silt loam	15	(0.5)
sandy loam	45	(1.5)
loamy fine sand	30	(1.0)
TOTAL	140	(4.7)

Boring A7

Material	Thickness, cm	(ft)
silty clay	60	(2.0)
silty loam	30	(1.0)
loamy fine sand	60	(2.0)
fine sand, brown	15	(0.5)
TOTAL	165	(5.5)

Boring A8

Material	Thickness, cm	(ft)
silty clay	105	(3.5)
loam	15	(0.5)
loamy very fine sand	30	(1.0)
TOTAL	150	(5.0)

SOUTH WETLAND (continued)

Boring A9

Material	Thickness, cm	(ft)
silty clay	90	(3.0)
loam	15	(0.5)
medium sand, dirty	45	(1.5)
TOTAL	150	(5.0)

Boring B1

Material	Thickness, cm	(ft)
silty clay	135	(4.5)
loam	30	(1.0)
silt loam	60	(2.0)
fine and medium sand	15	(0.5)
TOTAL	240	(8.0)

Boring B2

Material	Thickness, cm	(ft)
silty clay	195	(6.5)
silty clay loam	15	(0.5)
loamy sand	15	(0.5)
fine sand	45	(1.5)
TOTAL	270	(9.0)

Boring B3

Material	Thickness, cm	(ft)
silty clay, heavy	60	(2.0)
silty clay, light	30	(1.0)
sandy loam	15	(0.5)
loamy sand	30	(1.0)
fine to very fine sand	45	(1.5)
medium sand	15	(0.5)
TOTAL	195	(6.5)

Boring B4

Material	Thickness, cm	(ft)
coarse silt	45	(1.5)
silt loam	15	(0.5)
sandy loam	15	(0.5)
silty clay	105	(3.5)
fine sand	15	(0.5)
TOTAL	195	(6.5)

Boring C1

Material	Thickness, cm	(ft)
silty clay	135	(4.5)
silty clay loam	30	(1.0)
silt loam	30	(1.0)
sandy loam	60	(2.0)
loamy fine sand	45	(1.5)
TOTAL	300	(10.0)

Boring C2

Material	Thickness, cm	(ft)
silty clay, brown	185	(6.2)
silty clay, gray	45	(1.5)
clean fine sand, gray	30	(1.0)
TOTAL	260	(8.7)

Boring C3

Material	Thickness, cm	(ft)
silty clay	165	(5.5)
clean fine sand, gray	45	(1.5)
TOTAL	210	(7.0)

SOUTH WETLAND (continued)

Boring C4

Material	Thickness, cm	(ft)
silty clay	30	(1.0)
clay loam	15	(0.5)
loam, heavy	15	(0.5)
sandy loam	45	(1.5)
loamy fine sand	45	(1.5)
loam with secondary calcite	15	(0.5)
fine sandy loam	60	(2.0)
silty clay loam	30	(1.0)
loamy fine sand	30	(1.0)
TOTAL	285	(9.5)

APPENDIX B

Harrisonville wetland

Hydrogeology of the Harrisonville Wetland

A wetland occupying a swale in the Mississippi floodplain located in Section 16, T. 3 S., R. 11 W., Monroe County, was briefly examined in the field, and two piezometers were installed. In addition, several shallow test borings were drilled to characterize the alluvial deposits.

The geologic setting in which the Harrisonville wetland occurs is very similar to the settings of the north and south wetlands in the Big Five Districts. The wetland occupies a point bar or chute swale approximately 4 kilometers (2.5 miles) from the main channel of the Mississippi. The swale and surrounding ridges are underlain by fine to medium sand at depths ranging from 2 meters (6.5 feet) near the center of the swale to the surface on some portions of the ridges. Regional data suggest these sands are continuous with the major valley aquifer. The upper 1 to 2 meters (3.2 to 6.4 feet) of the swale-fill deposits are in most places tight silty clays and silty clay loams. If laterally continuous, these materials would form a substantial barrier to vertical ground-water flow; however, the lateral continuity of these deposits is not known.

The principal difference between the Harrisonville wetland and wetlands studied in the Big Five Districts is the absence of ditches to drain surface water from the swale. Piezometers installed at the site show water levels just below ground surface. Additional piezometer installations are necessary to measure hydraulic gradients and to identify the effect of river stage variations on the Harrisonville wetland. Preliminary data suggest that the wetland is more sensitive to river stage fluctuations than other wetlands studied.